Recommended Design, Operation, Closure and Post-Closure Approaches for Municipal Solid Waste and Hazardous Waste Landfills[1]

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Presented below is a summary of the approaches that the authors find should be followed in landfilling of hazardous waste and hazardous waste residues and municipal solid waste. This discussion focuses on the landfilling approaches used by the US EPA RCRA Subtitle C hazardous waste landfills and Subtitle D municipal solid waste landfills.

Current Landfilling Approach

As currently designed in the USA, Subtitle C and D landfills are of the "dry tomb" type in which an attempt is made to isolate the waste residues from moisture through the closure of the landfill with a low permeability, but not necessarily an impermeable cover. The minimum design requires that Subtitle D landfills be lined with a single-composite liner and Subtitle C landfills be lined with a double-composite liner.

Vertical monitoring wells are placed at the point of compliance for groundwater monitoring typically within 150 meters of the down-groundwater gradient edge of the landfill. These vertical monitoring wells are often spaced hundreds to a thousand or more feet apart along the vertical plane representing the point of compliance.

Post-closure maintenance and monitoring of the landfill is required for 30 years where the maintenance of the cover is funded at a level that only allows for superficial cover maintenance. The low permeability layer of the landfill cover will deteriorate over time allowing increasing amounts of moisture to enter the landfill generating leachate. In a typical Subtitle C or D landfill cover, the low permeability layer is buried below one or more feet of topsoil and, for many landfills, a drainage layer. As a result, visual inspection of the cover - typically the approach used to determine when the cover needs maintenance - will not detect significant cracks in the cover low permeability layer that will allow greater-than-designed moisture entrance to the landfill. The result is that landfill covers will permit much greater moisture to enter the landfill than predicted based on typical consultants' estimates. Such

[1]Reference as: Report to Greenpeace Mexico, G. Fred Lee & Associates, El Macero, California. 1995.

estimates are only applicable to the time at which the landfill's cover is constructed provided that high-quality construction is, in fact, achieved.

The moisture that enters the landfill generates leachate which when the landfill liner system is new and of high-quality construction and initial operation of the landfill is achieved, is largely collected in the leachate collection and removal system. However, over time the plastic sheeting flexible membrane liner will deteriorate and eventually become ineffective in collecting - transporting leachate to the sump where it can be removed. The compacted soil layer underlying the flexible membrane liner can transport significant amounts of leachate through it at design permeability. Further, there are a wide variety of factors, such as desiccation cracking, that cause the compacted clay layer liner to have poor efficiency in preventing leachate from passing through it. The US EPA (1988a,b) as part of developing Subtitle D regulations summarized the expected long-term performance of composite liners,

> *"First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills."*
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> *"Once the unit is closed, the bottom layer of the landfill will deteriorate over time and, consequently, will not prevent leachate transport out of the unit."*

Lee and Jones-Lee (1993) have discussed the ability of plastic flexible membrane liners to prevent leachate from passing through them for as long as the wastes in a landfill represent a threat. Typically, the wastes in either hazardous or municipal solid waste landfills will be a threat to public health and groundwater quality forever in a "dry tomb" type landfill.

Further, the groundwater monitoring approach allowed under Subtitle C and D for detecting liner leakage is a flawed technological approach toward reliably monitoring groundwater pollution by landfill leachate. As discussed by Lee and Jones-Lee (1994a), the vertical monitoring wells used have zones of capture of about one foot around each well. When they are spaced hundreds to a thousand or more feet apart, there is a high probability that the finger plumes of leachate produced by the initial leakage of leachate through the liner system will not be intercepted by the vertical monitoring wells with the result that large amounts of groundwater downgradient from the point of compliance can be polluted with leachate-derived constituents before the vertical monitoring wells detect this pollution.

The US EPA Subtitle C and D "dry tomb" landfilling approach is obviously a flawed technology that, at best, only postpones when groundwater pollution occurs by landfill-derived leachate.

There is need to revise RCRA and the US EPA Subtitle C and D regulations to develop landfilling approaches for municipal solid wastes and hazardous wastes that will in fact protect groundwater resources from pollution by landfill leachate for as long as the wastes in the landfill represent a threat.

Threat of Hazardous and Municipal Solid Waste Leachates to Public Health and Groundwater Resources

It is assumed in this discussion of landfilling of hazardous wastes in a Subtitle C landfill that the hazardous wastes have been treated at least to conventional TCLP standards so that there are no leachate components in the waste that exceed, under the conditions of the TCLP test, 100 times drinking water standards. It is important to note, however, that not all hazardous wastes placed in Subtitle C landfills are "treated" to TCLP standards. The US EPA and states allow the deposition of some types of hazardous wastes in Subtitle C landfills without treatment. While treatment to meet TCLP standards significantly reduces the hazard associated with many hazardous wastes, it does not eliminate it for the regulated chemicals and does not address the unregulated chemicals which may be the bulk of the hazardous substances in the hazardous waste.

The list of regulated chemicals is not based on a proper assessment of the constituents in hazardous waste that are hazardous to public health and the environment. It is largely an outgrowth of a lawsuit by environmental activist groups against the US EPA that resulted in a consent decree in the mid-1970s defining the Priority Pollutants. The Priority Pollutants, however, were selected without proper peer review by the technical community and did not include proper peer review within the US EPA. Some of the Priority Pollutant chemicals are of limited importance as constituents in hazardous wastes and threats to public health and the environment. However, there are many hazardous chemicals that are not listed as Priority Pollutants.

It has also been assumed in this discussion that the municipal solid waste that is deposited in a Subtitle D or equivalent landfill has been source separated to remove upwards of 50% of the recyclables such as certain forms of paper, yard waste, certain types of plastic, glass and aluminum and steel cans. It is also assumed that a typical county-operated, household hazardous waste collection program is in effect. Further, it is assumed that the landfill owner/operator is practicing typical periodic load inspection in an attempt to reduce the amount of highly hazardous chemicals present in the municipal solid waste stream that are normally deposited in Subtitle D municipal landfills. However, none of these practices significantly reduces the threat that municipal solid waste leachate represents to public health and the environment as well as the groundwater resources hydraulically connected to the landfill.

It is important to understand as discussed by Jones-Lee and Lee (1993) and Lee and Jones-Lee (1994b) that municipal solid waste of the type typically generated in the US today as well as "treated" hazardous waste to meet at least TCLP leachable standards still represents significant threats to public health, groundwater resources and the environment. This threat arises from a number of situations including the inability to truly control what are classified as hazardous wastes from entering the municipal solid waste stream that are deposited in landfills. Further, even if municipal solid waste deposited in the landfill could be freed of what are classified as hazardous wastes in accord with the US EPA procedures, the wastes would still be highly hazardous and detrimental to groundwater quality for use of the groundwaters as a domestic water supply.

The hazardous nature of municipal solid wastes arises from the fact that there are many hazardous waste constituents in the municipal solid waste stream which are not now regulated. For example, lead routinely occurs in urban soils at concentrations which are considered be highly hazardous to children and would be a hazardous waste if the soils were evaluated with respect to the leachability of the lead using standard US EPA procedures. Further, in some states such as California, the Department of Health Services has established Title 22 limits which make lead in most center city urban soils a hazardous waste. However, neither the federal nor the state regulations are enforced. The same situation applies to many other constituents that are present in the typical municipal solid waste stream.

Because of the typical factor of 10 difference in cost associated with the disposal of hazardous wastes and non-hazardous wastes, there is a significant economic incentive for commercial, industrial and homeowners to place hazardous wastes in the municipal solid waste stream. The load checking programs that are used are not effective in preventing illegal disposal of hazardous wastes in municipal solid wastes.

Another group of constituents in the municipal solid waste stream which are leachable in a municipal solid waste landfill and therefore of concern because they adversely impact groundwaters contaminated with municipal solid waste leachate are the conventional pollutants such as total salts, total organics which can impact the aesthetic quality through taste, odors, color, etc., iron, manganese, hardness, hydrogen sulfide, etc. All of these constituents are of concern with respect to domestic water supply water quality. Increases in concentrations cannot only adversely impact public health, but also the palatability of the water. Further, a number of these constituents are of economic importance to the public through increased corrosion, scale formation, etc. of distribution systems, plumbing fixtures and various appliances.

The third group of chemicals of concern associated with a landfill whether classified as hazardous or domestic waste is the unregulated non-conventional pollutants. Most of the organic carbon present in domestic solid waste leachate and hazardous waste leachate is of unknown characteristics. Only about 200 out of about 60,000 chemicals that are used in everyday commerce in the US are regulated today. The treatment of the hazardous waste to meet TCLP type standards for leachable components will not eliminate this problem. There is, therefore, a vast arena of potentially hazardous chemicals as well as chemicals that can be deleterious to domestic water supply water quality in both hazardous waste and municipal solid waste leachate.

It is because of the non-conventional pollutants that it should never be assumed that if a water meets drinking water standards (maximum contaminant levels) that this water is safe to consume if it is known to have been polluted by either hazardous waste or municipal solid waste leachate. There could readily be unregulated chemicals present in the leachate which are highly hazardous to public health even though the groundwater polluted with the leachate meets all drinking water standards.

Overall, both Subtitle C and D landfills receive wastes that represent highly significant threats to public health, groundwater resources and the environment. The current landfilling approach only postpones when groundwater pollution occurs for those landfills that are sited in areas in which the landfill is hydraulically connected to groundwaters that can be used for domestic water supply purposes at any time in the future. There is an obvious need for alternative landfilling approaches if public health and groundwater are to be protected from pollution by landfill leachate for as long as the wastes in the landfill represent a threat, i.e. forever.

Landfill Design, Operation, Closure and Post-Closure Care Performance Standards

Even though it has been well known since the 1950s that landfills represent significant threats to groundwater quality, it was not until about 1980 that regulatory approaches were adopted and implemented which were at least initially designed to prevent groundwater pollution by constituents in solid waste. Unfortunately, the US EPA made a serious error in developing the "dry tomb" landfilling approach. This appears to have evolved out of the significant mistake that was made in assuming that landfills only represented a threat for 30 years after closure. As discussed by Lee and Jones-Lee (1993b, 1994b), the mandated 30-year post-closure care period appears to have evolved out of the misconception that the normal sanitary landfill's 30 to 50 year landfill gas production period was the only issue of concern. While landfill gas is an important potentially hazardous emission from landfills, often of even greater importance is the potential to pollute groundwater by landfill leachate. Landfill gas production and landfill leachate production are not directly linked. One is a bacterial fermentation process in which certain organic constituents in the wastes are converted to landfill gas (CH_4 and CO_2). In a typical sanitary landfill appreciable precipitation can enter the landfill through the cover. This leads to the conversion of the fermentable organics to landfill gas which typically occurs over a 30 to 50 year period.

The leaching of chemical constituents from hazardous waste and municipal solid waste can take place in a classical sanitary landfill for thousands of years and still produce a leachate that is significantly adverse to groundwater quality. Belevi and Baccini (1989) have developed a model that predicts that conventional sanitary landfills in Switzerland will be threats to groundwater quality through the leaching of lead that is normally present in municipal solid waste for over 2,000 years.

In the "dry tomb" landfill, the period of time will be extended to the extent that the "dry tomb" character of the landfill is, in fact, achieved and maintained. With little or no moisture in the landfill, the wastes will remain unfermented and unleached. However, as soon as those responsible for maintenance of the "dry tomb" provide inadequate maintenance and moisture enters the landfill, then the process of environmental pollution associated with landfill gas and leachate emissions from the landfill will proceed. If this process occurs early in the post-closure period while the liner system is still functioning relatively effectively, the leachate that is generated in the landfill will, at least to some extent, be collected in the leachate collection and removal system. In time, however, the efficacy of the leachate collection and removal system to remove leachate will deteriorate due to the deterioration of the flexible membrane liner(s) and in effect become non-functional in collecting sufficient leachate to prevent groundwater pollution.

While there is insufficient information on the long-term characteristics and use history to reliably predict the period of time when the FML liner will fail to be effective in collecting and removing leachate, it is likely to be on the order of a few decades and may be on the order of 100 or so years. There is no question, however, that ultimately the wastes will be a significant threat to groundwater pollution far longer than the "dry tomb" liner systems, including double-composite liners, that will prevent leachate generated in the landfill from entering groundwaters near the landfill. The inorganic salts, heavy metals and many organics will be a threat to groundwater quality effectively forever. Even if the liner system is effective in preventing leachate from passing through it for 100 or so years, still at the end of this period, future generations will face pollution of their groundwater resources by leachate from today's Subtitle C and D landfills. Therefore, rather than planning the post-closure maintenance period for 30 years as is currently practiced for Subtitle C and D landfills, the post-closure care maintenance period should assume that leachate can be generated in the landfill for as long as the landfill will exist which in most cases will be forever.

The state of California Water Resources Control Board adopted Title 23 Chapter 15 regulations in 1984 which set forth the overall performance standard for landfills developed in that state to, as a minimum, protect groundwater quality from impaired use from all constituents for as long as the wastes in the landfill represent a threat. This is the only sensible regulatory approach for establishing landfill containment system design performance standards whether hazardous or non-hazardous.

It is important not to confuse minimum landfill containment system component design standards set forth in Subtitle C and D and state regulations with the overall landfill containment system performance standard. The purpose of the containment system (liners, leachate collection and removal and cover) is obviously to prevent pollution of groundwaters by landfill leachate. Regulatory agencies at the federal and state level specify minimum landfill individual component design standards that can be used in some situations. Today, however, landfill applicants, their consultants and some regulatory agencies are allowing Subtitle C and D landfills to be constructed which only utilize minimum individual containment system component design standards, such as a single-composite liner for a Subtitle D landfill. It is obvious, however in review of such landfills, that using the minimum design standard for a component of the containment system set forth in the regulations will not achieve the overall landfill containment system performance standard of protecting groundwaters from pollution from landfill leachate for as long as the wastes in the landfill represent a threat. It is very important that in review of the liners, covers, groundwater monitoring systems, etc., for a landfill that an evaluation be made of whether the overall containment system components will be protective of public health and the environment for as long as the wastes represent a threat.

Designing landfills which will only postpone when groundwater pollution occurs, such as is typically being done in the US today, represents a short-sighted, selfish approach on the part of those who generate the wastes today who through this approach are able to pay less for their solid waste management than the true real cost. These costs, however, are passed on to future generations. The proper management of municipal solid wastes should require that those who generate the waste pay a few cents per day more for their garbage disposal than what they are currently paying for minimum Subtitle D disposal. Further, a small percentage increase in the cost of goods that generates the hazardous wastes that are managed in Subtitle C landfills would provide the funds necessary to properly protect future generations' groundwater resources from impairment of use by inadequately designed, operated, closed and maintained "dry tomb" landfills.

The basic question that needs to be addressed is can "dry tomb" landfills be modified so that they will, in fact, provide for true public health, groundwater resource and environmental protection for as long as the wastes in the landfill represent a threat? As discussed below, technology is being developed today that will enable "dry tomb" landfills to be a technically-valid approach for managing municipal solid waste and treated hazardous waste residues. Unfortunately, the implementation of this technology is limited since as long as the regulatory agencies at the local, state and federal level allow landfilling at less-than-real cost, landfill owners and operators will continue to opt for the initial cheaper-than-real cost disposal of waste in order to remain competitive.

Modification of Subtitle C and D Landfills to Provide for True Public Health, Groundwater Quality and Environmental Protection

Landfill Liner Design. All "dry tomb" type landfills whether for hazardous wastes and residues or municipal solid waste should be designed with a minimum of double-composite liners with a leak detection system between the two composite liners. This leak detection system should be a high permeability layer of sand or other media that is not subject to significant clogging by leachate-induced biological growths. It should be understood that the lower composite liner is not a containment liner but is part of the upper composite liner leak detection system, i.e. a full landfill area pan lysimeter. This is the approach which was adopted by the state of Michigan in its Rule 641 governing landfilling of municipal solid wastes.

The key protection of groundwater quality in a double-composite lined landfill where the lower composite liner's function is primarily that of a leak detection system for the upper composite liner is the ability to take appropriate action when leachate is found in the leak detection system between the two composite liners. When leachate is found there that could result in groundwater pollution if the second composite liner were not present, it has to be assumed that the upper composite liner has failed. At that time, if the landfill owner/operator cannot stop the leachate from entering the leak detection system below the upper composite liner, then there is no alternative but to remove the wastes from the landfill since it is only a matter of time until there will be failure of the second composite liner and pollution of any groundwaters associated with the hydrogeologic system in which the landfill is located.

Landfill Covers. The key to developing a "dry tomb" type landfill that will protect groundwater quality for as long as the wastes represent a threat from impairment by landfill leachate is the ability to provide an impermeable cover on the landfill. Current Subtitle C and D landfill covers contain a low permeability layer. However, this layer will not prevent moisture from entering the landfill. Substantial moisture can enter the landfill through the cover due to a variety of mechanisms through cracks, holes, rips and tears in the plastic sheeting of the cover as well as differential settling-caused cracks and desiccation-caused cracks in any compacted clay layers that are present in the cover.

Frequently, landfill applicants and their consultants claim that, since the annual moisture gradient for a landfill located in arid areas of the US is to the atmosphere, no leachate can be generated in the landfill. It is inappropriate to use net annual moisture flux direction to estimate the potential for leachate generation. Short periods of high moisture input, such as after a moderate to intense precipitation event, do allow sufficient moisture to enter the landfill generating leachate that can lead to groundwater pollution.

Another mistake that is commonly made is to assume that the moisture-holding capacity (field capacity) of the wastes must be exceeded before the wastes will generate leachate that can pollute groundwater. Such an approach ignores unsaturated transport of leachate-derived constituents in the waste and in the underlying aquifer. While landfills in desert areas produce less leachate than landfills in wetter areas, the arid area landfills generate sufficient leachate to pollute groundwaters. Small amounts of moisture can generate leachate that, because of the strength of MSW leachate, pollutes substantial amounts of groundwater rendering them unusable for domestic water supply purposes.

Until about two years ago, it was concluded that inevitably all "dry tomb" type landfills will fail and if there is an interest in protecting groundwater resources hydraulically connected to the landfill from pollution by landfill leachate, it would be necessary to exhume the wastes from the landfill. In the past couple of years, however, two commercially available leak testable landfill cover systems have been developed which have changed this situation. The Robertson system (Robertson Barrier System Corp., Vancouver, BC, CANADA) utilizing a double FML sandwiched on a geonet in which a vacuum is applied to the sandwiched FMLs, can detect when there are holes in one of the FMLs, and therefore indicate the need for repair. Also, Gundle Lining Systems Inc. of Houston, Texas, USA, has imported an electrical leak detection system for FMLs from Europe which can be used to detect holes in the FML in a landfill cover and thereby indicate the need for repairs in a specific area of the cover.

Installing a leak-detectable cover and its *ad infinitum* operation and maintenance can create a true "dry tomb" that will prevent leachate formation; however, these covers must be operated and maintained forever. Additional information on landfill post-closure issues and the use of leak detectable covers is provided by Lee and Jones-Lee (1995a).

Funding "Dry Tomb" Landfill Post-Closure Care Activities

One of the most significant deficiencies of Subtitle C and D regulations is the failure of the US EPA and the states to properly assure funding of Subtitle C and D landfill post-closure care activities for as long as the wastes in the landfill will be a threat. As discussed above, the US EPA made a significant error in implementing Subtitle C and D landfilling requirements in only mandating 30 years of assured post-closure care. The basic problem is within RCRA and the advice given to Congress in formulating RCRA. The US EPA could have through its interactions with Congress pointed out the significant errors that Congress made in establishing RCRA with respect to post-closure care funding. However, the Agency at that time chose not to do so with the result that, at this time, all landfills based on RCRA requirements that are being developed in the US do not have the assured funding that will be necessary to provide true public health, groundwater resource and environmental quality protection for waste-derived constituents for as long as the wastes in the landfill represent a threat.

The GAO (1990) reviewed the hazardous waste landfill post-closure care funding situation and concluded that funding is not necessarily available to meet expected contingencies including eventual clean-up of contaminated groundwaters associated with the landfill when the liner systems fail to collect the leachate generated within the landfill to a sufficient extent to prevent significant groundwater pollution.

While it could be argued that the additional funding that will be needed in year 31 and beyond after closure will become available, the likelihood of this being the case is small. All one has to do to understand this situation is to examine how governmental agencies at the federal, state and local level are now closing former dumps and sanitary landfills. There are many tens of thousands of dumps and landfills across the US that are polluting groundwaters that have not been addressed with respect to stopping this pollution primarily because the local communities responsible for the landfills claim that they do not have the funds available to require that the landfill be properly closed and that the polluted groundwaters be cleaned up to the maximum extent practicable. The same situation will likely occur at most Subtitle C and D landfills where future generations will face the same problems of trying to find funds to stop further pollution of the groundwater resources in the vicinity of the landfill by leachate and to clean up the pollution that has already occurred.

Hickman (1995), Executive Director of the Solid Waste Association of North America in an article entitled, "Ticking Time Bombs?" discusses the inadequacy of the current approaches that are frequently used for providing assured long-term funding for post-closure care activities for today's landfills. He states,

> *"I think that what we have done, in those instances where these landfills do not have a dedicated trust fund, is to build another generation of ticking time bombs that will go off after we have gone. When that occurs, sometime in the future another generation of Americans will be left with a bill to pay that we should be paying now."*

Hickman (1992) discusses the problems with many of the financial instruments used today to "assure" that funds will be available to meet post-closure care needs and contingencies for today's "dry tomb" landfills. He points out that today, the only reliable financial instrument to assure post-closure care needs is a dedicated trust derived from waste disposal fees. Adding a few cents per day per person to the cost of solid waste disposal which is placed in a dedicated trust can generate sufficient funds to ensure that funds will be available when needed in perpetuity to meet landfill post-closure care needs and contingencies. Lee and Jones-Lee (1993b) provide further discussion of the importance of utilizing a dedicated trust derived from disposal fees to provide the funds needed for Subtitle C and D landfills.

Alternative Waste Disposal Practices

While the US EPA adopted the "dry tomb" landfilling approach for hazardous and municipal solid wastes, other countries have examined this approach and determined that it is a technically flawed approach to provide true groundwater quality and public health protection from waste components. Increasing recognition is being given in the US and in other countries to the need to treat municipal solid wastes, either before burial or at the time of burial within the landfill (*in situ* treatment), in order to eliminate the pollution of groundwaters by landfill leachate.

Germany (Rebitzer 1995) has adopted regulations that require that the municipal solid wastes contain no more than 3% organics at the time of burial. While this approach will reduce some of the groundwater pollution and landfill leachate problems associated with municipal solid waste landfills, it will not eliminate the significant problems associated with the pollution of groundwaters by MSW caused by heavy metals and other inorganic constituents and the residual organics in the treated MSW.

In the US, increasing attention is being given to the use of municipal landfill leachate recycle where leachate developed in the landfill is introduced back into the landfill. Such practices increase the hydraulic loading on the landfill and thereby can stimulate the conversion of fermentable organics into landfill gas. While this approach is said to "stabilize" a landfill, the word "stabilize" is often misinterpreted since leachate recycle as it is being practiced, does not address the most important problems associated with municipal solid waste landfills, namely the pollution of groundwaters by leachate. Landfill leachate recycle, as being practiced in Subtitle D landfills, has a very high probability of causing increased groundwater pollution due to the increased hydraulic loading and the inability to detect holes or other problems in the liner system before widespread groundwater pollution occurs.

While leachate recycle changes the composition of leachate with respect to some of the organic fractions, it does not address many of the problem areas associated with municipal solid waste landfills. Further, leachate recycle as typically practiced in which untreated wastes are placed in the landfill, will not likely be effective in converting the fermentable organics into landfill gas in a short period of time since much of the waste will be contained within plastic bags that will only slowly degrade within the landfill.

Lee and Jones-Lee (1993c, 1995b) have recommended that a true wet-cell approach be used in all leachate recycle projects where a double composite-lined landfill is constructed in which the lower composite liner is a leak detection system for the upper liner in order to ensure that no pollution of groundwaters occurs because of the increased hydraulic loading on the landfill associated with leachate recycle. Further, they recommend that all wastes placed in the landfill be shredded and that for a period of about five years, leachate generated in the landfill be recycled back into the landfill to enhance landfill gas formation. Once the gas formation phase of the wastes in the landfill has been essentially completed, then the shredded wastes are washed (leached) with clean water in order to remove those constituents that represent long-term threats to groundwater pollution through leachate formation. During the clean water leaching of the wastes, no leachate recycle is practiced. Instead the leachate is treated and disposed of after adequate treatment in nearby water courses.

The true wet-cell approach involving the clean water washing of the garbage to remove leachable components after "stabilization" with respect to landfill gas formation will produce a residue within 10 to 20 years that would represent little threat to groundwater quality. This *in situ* treatment period would be expected to be within the effective lifetime of the liners used as the base for the leachate collection and removal system for a single composite lined landfill, provided that high quality construction occurs for the landfill liner system and that holes or unusual stresses are not placed on the landfill liner system associated with the deposition of wastes in the landfill.

At this time, the clean water leaching of wastes in a Subtitle D landfill would not be allowed since the addition of liquids to the landfill, other than leachate, is prohibited by RCRA. There is need to change RCRA so that true, *in situ* treatment of the wastes in the landfill can be practiced.

The wet-cell approach for managing municipal solid wastes, while initially slightly more costly than a conventional "dry tomb" approach, in the long term will be far cheaper as a result of eliminating the long-term liabilities associated with groundwater clean up. Further, the wet-cell approach eliminates the high maintenance costs associated with maintaining a "dry tomb" landfill in perpetuity.

Addressing NIMBY

While the US EPA in developing Subtitle D regulations claimed that these regulations will address legitimate NIMBY (not in my backyard) issues, in fact Subtitle D failed to properly address a variety of NIMBY concerns of individuals living within the sphere of influence of a Subtitle C or D landfill. Groundwater pollution and management of landfill gas are only some of the adverse impacts that landfills represent to the interests of those who own or use properties near them. Lee and Jones-Lee (1993d, 1994d) have discussed the variety of adverse impacts that siting a municipal solid waste or industrial hazardous waste landfill without adequate land buffer and other provisions can have on those who own or use properties within the sphere of influence of the landfill. These include, in addition to groundwater pollution and landfill gas impacts:

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• illegal roadside dumping and litter near landfills (aesthetics, public health, economics), • truck traffic, • noise, • odors, • impaired view, • dust and wind-blown litter, • vectors, insects, rodents, birds (nuisance, public health), • condemn adjacent properties for future uses, • decrease property values. Many of these issues were not addressed in Subtitle D regulations. Further, they are inadequately addressed in state regulations.

Many of these problems are associated with the active life (period of waste deposition) of the landfills. They can be addressed by requiring that the landfill owner acquire sufficient buffer lands as part of landfill development to allow dissipation of the adverse impacts on landfill owner owned lands so that at the property line with adjacent property owners, there are no adverse impacts to the adjacent property owners other than an altered view and the truck traffic associated with the landfill operations. The sphere of influence of a landfill often extends for several miles from the waste deposition areas. Decreases in property values are often found over this distance.

Lee and Jones-Lee (1993d, 1994d) recommend that in addition to controlling the controllable adverse impacts associated with landfill operations that those who generate the wastes and do not want the landfill located near them contribute a few cents per person per day to the property owners - users within the sphere of influence of the landfill to compensate them for the non-controllable adverse impacts of having a landfill sited in their vicinity. Adoption of this approach would go a long way towards eliminating justifiable NIMBY and greatly facilitate the siting of properly designed, constructed, operated, closed and maintained landfills. The federal and state regulations governing the landfilling of wastes should be changed to ensure that all adverse impacts of landfills that are controllable are controlled within the property boundaries of the landfill owner. This will generally require at least a one-mile buffer of land in which no waste deposition takes place. There may be situations where more than one mile of bufferlands will be needed.

Conclusion and Recommendations

Today's US EPA Subtitle C and D hazardous and municipal solid waste landfills utilize a flawed technological approach for the development of a landfill containment system that at best only postpones when groundwater pollution occurs. There is need to change RCRA and/or state regulations:

- require that a double-composite liner be used for both Subtitle C and D landfills where the lower composite liner is a leak detection system for the upper liner.

- require that when the landfill owner/operator cannot stop leachate from occurring in the leak detection system between the two composite liners that the wastes in the landfill must be removed from the landfill.

- require the closure of Subtitle C and D landfills with leak detectable covers that are operated and maintained for as long as the landfill exists.

- eliminate the minimum 30 year post-closure care and maintenance period and require that post-closure care be provided for as long as the wastes in the landfill represent a threat which is understood in a "dry tomb" type landfill to be forever.

- require than an adequate dedicated trust fund be developed from disposal fees to ensure that funds will in fact be available when needed for perpetual monitoring, maintenance, care and to meet any plausible worst-case contingencies that could occur at a landfill including waste exhumation and clean up of polluted groundwaters.

- allow *in situ* treatment utilizing clean water leaching of the wastes in double composite lined landfills.

- RCRA needs to be changed to ensure that all justifiable NIMBY impacts associated with landfills are controlled within the property boundaries of the landfill owner.

Because of the very high perpetual, *ad infinitum* costs associated with "dry tomb" landfilling that provide for true protection of public health, groundwater resources and the environment, it is recommended that the "dry tomb" landfilling approach be abandoned as soon as possible in favor of a waste-treatment approach that produces residues that do not represent long-term threats to groundwater quality, public health and the environment.

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